THE ENERGETICS OF GAS-FILLED HOHLRAUMS

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Introduction

The x-ray drive generated in a laser-driven hohlraum ablates the high-Z wall material[1–3] that can then fill the hohlraum with a high-density plasma during the laser pulse. This high-Z plasma absorbs the laser energy in regions well removed from the original location of the hohlraum wall. Because this plasma is high-Z, the conversion from laser energy to x rays can occur in a volume of the hohlraum that is not as well localized as the original hohlraum wall location, and this in turn can effect the drive symmetry in an unwanted way.[4] To mitigate the problems associated with this high-Z filling of the hohlraum, a low-Z material is introduced to tamp the high-Z wall.[5] This tamper is typically less than one-tenth of the critical density n_c for the laser light used to illuminate the hohlraum. However, the pressure associated with the tamper is sufficient to keep the hohlraum wall material from moving significant distances into the hohlraum interior, thus preventing the laser deposition region from moving large distances during the laser pulse.

In the experiments we discuss here, the tamper is generated from a gas that is confined in the hohlraum. These gas-filled hohlraums must be designed with low-mass windows over the laser entrance holes (LEHs) and diagnostic holes to confine the gas. Thin (3500-Å) polyimide ($C_{22}H_{10}N_2O_5$) windows cover all of the apertures to provide a gas-tight seal. The laser light rapidly burns through the windows and gas, heating and ionizing the low-Z material as it propagates to the hohlraum wall. In the standard scale-1 Nova hohlraums, this occurs in about 200 ps. We have studied the effect of methane (CH_4), propane (C_3H_8), and neopentane (C_5H_{12}) on the hohlraum performance. When fully ionized, these gases at 1 atm generate plasmas with 0.025, 0.04, and 0.1 n_c, respectively. As the hohlraum wall moves inward, this low-Z plasma is compressed and the density is slightly higher than the "atmospheric" densities.

The laser beam interacting with the low-density plasma can generate parametric instabilities that can scatter the laser light.[6] If this scattered laser light leaves the hohlraum, this reduces the energy available to produce the x-ray drive. This article presents the results of hohlraum energetics measurements that are designed to quantify the energy losses in gas-tamped hohlraums. The hohlraum drive is characterized by a Planckian distribution of x rays that defines the hohlraum temperature. We determine this hohlraum temperature by measuring the radiation associated with the interior hohlraum wall, which differs slightly from the actual hohlraum temperature. In addition, we measure the time-dependent losses associated with the stimulated processes: stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS).[6]

Measurements of Hohlraum Energy Balance

Hohlraum Temperature Measurements

The gas-tamped hohlraums (shown in Fig. 1) are required to hold 1 atm of the desired tamping gas (CH_4, C_3H_8, or C_5H_{12}). This conventional scale-1 Nova hohlraum (2700 μm long and 1600 μm diam) has 75% LEHs (1200 μm diam) and a nominal 500-µm-diam Dante hole, which is lined with Be to reduce the closure of this aperture during the drive pulse. The Dante hole is positioned 20° down from horizontal in the hohlraum's midplane. All of the apertures are covered

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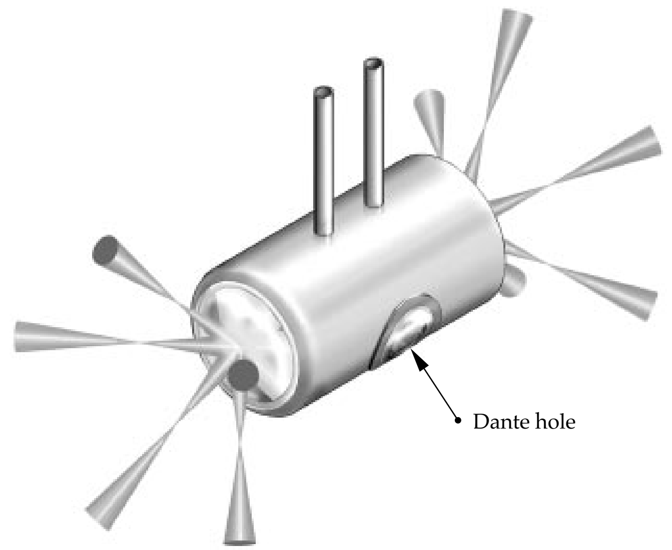

FIGURE 1. Schematic of a gas-filled hohlraum, showing five laser beams entering from each end. The fill gas is admitted through small tubes in the top of the hohlraum. The hohlraum temperature is monitored with an absolutely calibrated time-dependent soft x-ray spectrometer (Dante) that monitors the x-ray emission from the hohlraum wall through a small aperture. All of the apertures are covered with a 3500-Å polyimide membrane to provide a gas-tight seal. (08-00-0596-1242pb01)

with a 3500-Å-thick polyimide membrane to provide a gas-tight seal. The gas enters the side of the hohlraum through two stainless-steel tubes (260 μm o.d. and 80-μm wall thickness). The total area occupied by these tubes is insignificant to the total interior area of the hohlraum.

Nova drives the hohlraum with five beams on each end, and the laser pulse is shaped in time with a foot and a peak. Figure 2 shows examples of the incident laser pulse shape, illustrating the laser power as a function of time and the SBS and SRS time histories, for an empty and a C_5H_{12}-filled hohlraum.† The laser beams are aimed at the center of the LEHs and defocused 1000 μm to give a laser spot size of 400 × 600 μm at the hohlraum wall. The spatially averaged laser intensity at the hohlraum wall (without subtracting the SBS and SRS losses) is then $\sim 3 \times 10^{14}$ W/cm^2 in the foot and rises to $\sim 10^{15}$ W/cm^2 in the peak of the pulse.

The hohlraum temperature is measured with Dante,[7] which is an absolutely calibrated 10-channel, time-resolved soft-x-ray spectrometer. This diagnostic is located on the target chamber wall and views the hohlraum midplane along a line-of-sight 72° from vertical. The Dante views a section of the hohlraum wall that is not illuminated by the laser beams.

†The absorbed laser power is the difference between the incident and scattered laser power.

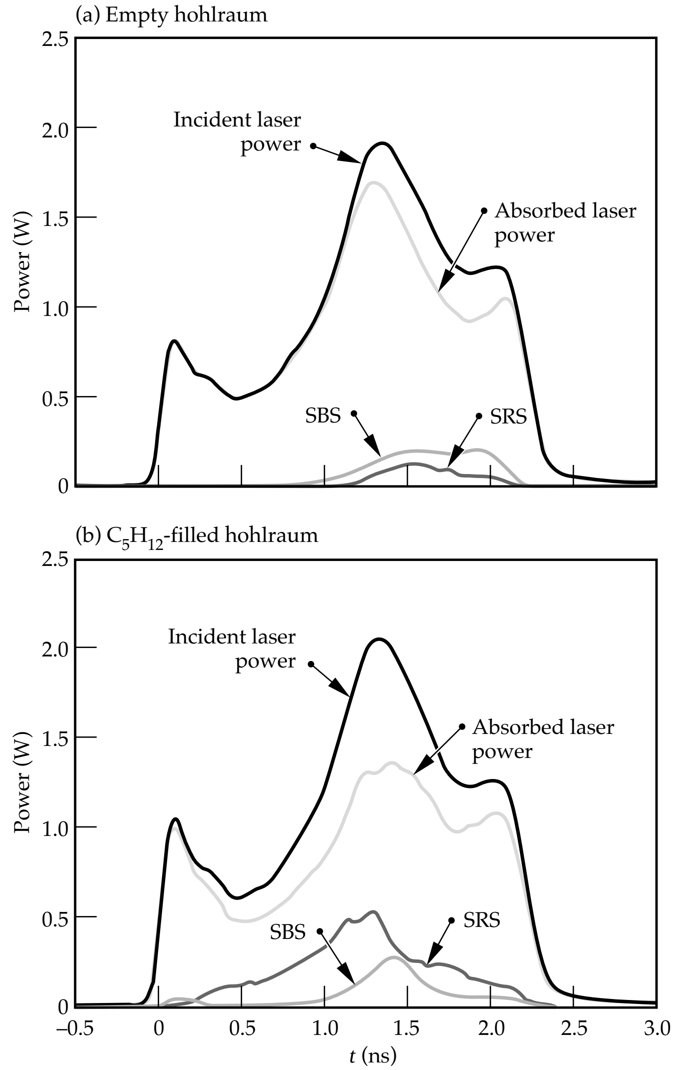

FIGURE 2. Measured incident laser pulse and the measured SRS and SBS for (a) an empty hohlraum and (b) a C_5H_{12}-filled hohlraum. The absorbed laser power is the difference between the incident power and the backscattered optical signal. (20-05-0796-1549pb01)

Dante measures the hohlraum wall temperature, which differs from the actual hohlraum temperature by a factor of the albedo (x-ray re-emission coefficient) to the 0.25 power. This corresponds to about a 5% correction to the hohlraum temperature, or ~10 eV at the peak of the drive. All of the measurements shown here correspond to the Dante (or wall) temperature.

Figure 3 shows the Dante measurements for various gas-filled hohlraums (the temperature histories for empty hohlraums with no windows; empty hohlraums with windows on the LEHs but no gas fill; and hohlraums filled with CH_4, C_3H_8, or C_5H_{12}). Each curve corresponds to two or three measurements with the same configuration (windows and/or gas fill), and the error bars correspond to the minimum and maximum measurement at each configuration. These data

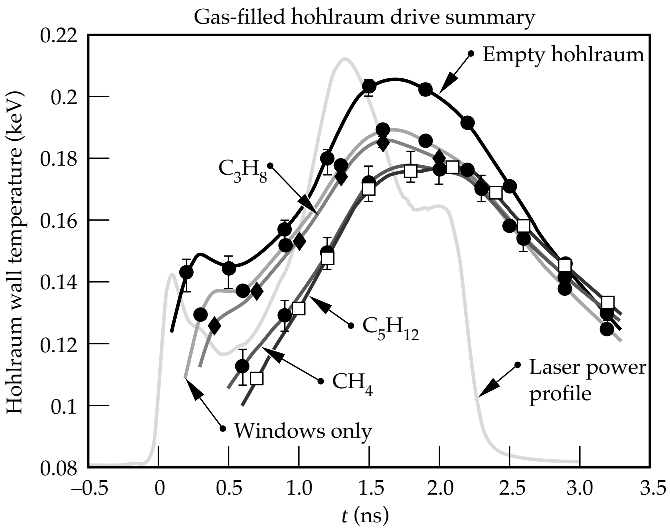

FIGURE 3. Hohlraum wall temperature as a function of time for empty hohlraums (with and without windows) and hohlraums with different gas fills (CH_4, C_3H_8, and C_5H_{12}). (20-05-0796-1548pb01)

show the drive to be quite reproducible. As expected, the addition of the gas causes an overall drop in the hohlraum temperature. However, the magnitude of the temperature drop cannot be attributed solely to the heat capacity of the gas and window material.

Two features are immediately apparent. First, the foot of the x-ray drive is significantly degraded in the hohlraum with windows only and the gas-filled hohlraum. This is due to the laser energy expended burning through the windows and then propagating through the gas. The small peak at the beginning of the laser pulse has completely disappeared, and the foot of the x-ray drive pulse rises more slowly. Second, the peak temperature decreases as the plasma density increases. Only a small part of this temperature decrease is attributable to the heat capacity of the gas; the major reduction in hohlraum drive can be attributed to backscattering (SRS and SBS) in the gas (discussed in the following section). Another interesting observation is the drop in temperature when the hohlraum has windows only and no gas. As can be seen from the data, the largest single temperature drop occurs when windows are added to the hohlraum.

Backscattered Energy Measurements

Nova's beamline 7 (BL7) is equipped with diagnostics[8] to monitor the laser energy that is reflected from the hohlraum via SBS and SRS. The diagnostics include calorimeters to monitor the total backscattered optical light energy (via each of the two processes) and streaked spectrometers to give the time-dependent optical spectra associated with each of the scattering mechanisms. The full aperture backscatter station (FABS) measures the radiation reflected back into the $f/4.3$ lens while the near beam imager (NBI)[9] monitors the optical light scattered at angles up to 20°. The temporal evolution of the backscattered radiation is inferred from normalizing the frequency- and time-integrated spectrum to the total backscattered energy.

Figure 4 shows the total reflected energy for the various gases and for the empty and windows-only hohlraums. In the empty hohlraum, most of the energy is reflected via SBS (6%) while an additional 3% is lost via SRS. When gas is introduced, the SRS becomes the dominant backscatter mechanism. The SRS level increases with the electron density n_e. While the time-integrated fraction of energy that is backscattered via stimulated processes can reach significant levels (~25% SRS + SBS in the C_5H_{12}-filled hohlraums), the time-dependent backscatter shows that during the laser pulse, the levels of backscatter can be even higher (see Fig. 2). Most of the scattered energy is associated with the main peak of the laser pulse, which starts about 1 ns into the pulse. This corresponds to the time at which the SRS and SBS gains are the largest due to the higher laser intensities (in the latter part of the pulse).

The laser beams used in these experiments are the standard, unsmoothed Nova laser beams. These beams include hot spots that can achieve intensities in excess of the average intensities quoted above. These higher intensities can exacerbate the growth of instabilities. To mitigate the problem of energy lost through backscattering, we intend to smooth the laser beams with random

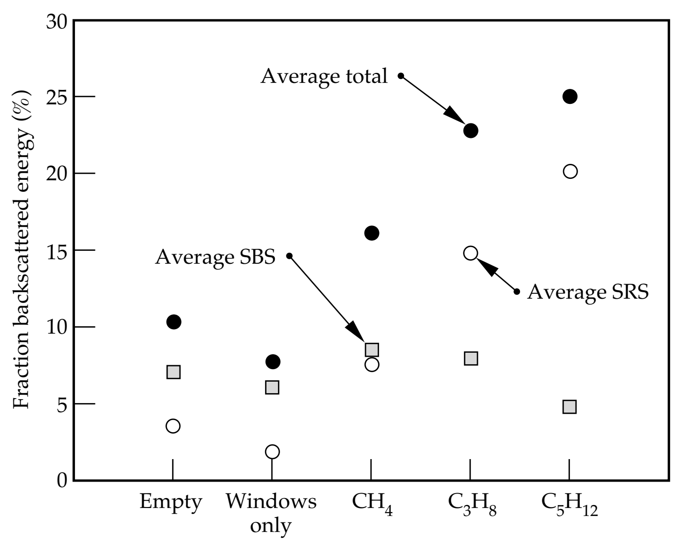

FIGURE 4. Fraction of backscattered laser energy (SRS, SBS, and their sum) for various hohlraum configurations (empty or windows only) and from hohlraums with various gas fills (CH_4, C_3H_8, and C_5H_{12}). (20-05-0796-1551pb01)

phase plates (RPPs) or kinoform phase plates (KPPs).[8] Figure 5 shows the effect of beam smoothing on the backscattered laser signal. We show the total backscatter levels for CH_4- and C_3H_8-filled hohlraums, using the standard Nova beam and a beam (BL7) smoothed with either a RPP or a KPP. The backscattered signal from the smoothed beam is a factor of 4 to 6 less than that for the unsmoothed beam.

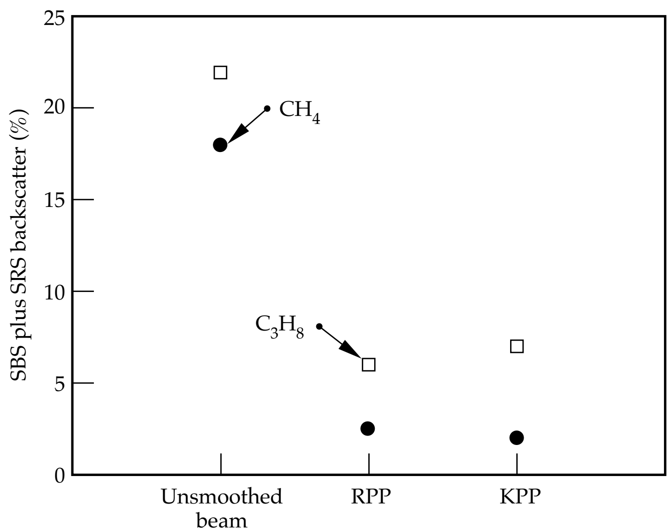

FIGURE 5. Fraction of backscatter laser energy (SRS plus SBS) in CH_4 or C_3H_8 gas corresponding to an unsmoothed laser beam and a laser beam smoothed with a random phase plate (RPP) or a kinoform phase plate (KPP). (20-05-0796-1550pb01)

An anomaly in these data is the energetics of the hohlraum with windows only. Note that the total backscatter fraction is slightly less than that for the standard, empty hohlraum. However, the temperature drop shown in Fig. 3 indicates a significant difference in absorbed energy. Comparing the integral over time of the radiated power (T_r^4) shows a difference of approximately 30% in total radiated energy while the backscatter energy shows virtually no difference. Looking again at Fig. 3, we see that the largest single energy difference is associated with attaching the windows to the hohlraum. We can speculate that the hohlraum is somehow contaminated in the process of installing the windows and that this contamination carries over to the remainder of the hohlraums with gas. On another series of measurements (less complete and with a slightly different temporal profile to the laser pulse), we saw a much smaller temperature drop associated with the hohlraum with windows only and no gas fill. There was no corresponding change in the relative levels of SRS and SBS. The contamination, if it is the problem, then, is associated with the fabrication technique and can vary from one set of hohlraums to another.

Modeling the Hohlraum Energetics

We use LASNEX[10] to simulate the time-dependent drive in the gas-tamped hohlraums. This code does not calculate the SBS and SRS losses; these losses are incorporated by using the net absorbed laser energy (i.e., measured incident minus SRS and SBS losses) in the calculation. We find that the code does not quite predict the level of temperature reduction that is observed in the experiment. The observed temperature drop in the CH_4-filled hohlraum is 20 eV, while the calculated temperature drop is 12 to 17 eV. This corresponds to a measured reduction in flux of 32% and a calculated reduction in flux of 21 to 28%. Similarly for C_3H_8, the measured reduction in temperature (flux) is 26 eV (40%), while the calculated drop in temperature (flux) is 18 to 21 eV (30 to 34%). This range in calculated temperature drop arises from a difference in calculated vs measured temperature as a function of time. The calculated temperature reaches a peak later in time. Simply comparing the peak calculated vs peak measured temperature results in a smaller difference. Looking at the calculated temperature at the time the measured temperature reaches a peak results in the larger difference.

In the modeling, there are two reasons for the reduction in drive in the gas-filled hohlraums. First, the radiation production is reduced because of the tamper. In the untamped hohlraum, the axial stagnation of the high-*Z* plasma is itself a source of radiation production. In the simulation, this reduced radiation production results in a temperature drop of 4 to 6 eV. Second, the drive is reduced due to decreased laser absorption (SRS and SBS). As mentioned, this part of the physics is added through the measured input power minus the measured SRS and SBS. In the simulation, this results in a 10- to 15-eV temperature drop.

Summary

We measured the time-dependent drive in gas-tamped hohlraums and compared the measurements with simulations. The addition of the gas tamper can result in as much as a 25-eV reduction in peak drive temperature. The overall drop in flux is as much as 40%, which is about 15% more than predicted by LASNEX simulations. Future experiments will use smoothed laser beams that will significantly reduce the levels of backscatter losses. Since these losses are not calculated by LASNEX, the new measurements will lend themselves to more accurate simulation.

Notes and References

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